**23rd International Conference on**
**Harmonisation within Atmospheric Dispersion Modelling**
**for Regulatory Purposes**
***15-19 September 2025, Hamburg, Germany***

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## EXTENDED ABSTRACT

# *Simulations using the MicroSwiftSpray modelling system in the frame of the EXPO-URB project*

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***Abstract.*** In the frame of a model intercomparison and valitation for the EXPO-URB Project, a sensitivity analysis was performed varying the input and the parameterisations in the modelling system MicroSwiftSpray. The focus was on the driving wind profile used in MicroSwift and the calculation of the turbulent parameters for the Lagrangian particle dispersion model MicroSpray. Different formulations were used and the changes induced by them in the simulation results are here presented and discussed. A main finding is the role of the Lagrangian time scale in determining the spreading of the plume, thus affecting the agreement with the measured values.

***Keywords:*** *Lagrangian particle models, Wind Tunnel experiments, Model Sensitivity Analysis*

## INTRODUCTION

In the frame of the EXPO-URB Project, model simulations have been carried out using the Parallel version of MicroSwiftSpray modelling suite (PMSS, Tinarelli et al., 2012), which includes the diagnostic meteorological reconstructor SWIFT and the Lagrangian Particle Dispersion Model SPRAY. The modelling system is suitable to perform simulations at very high resolution, explicitly considering the presence and the effects generated by the buildings located inside a computational domain. The EXPO-URB experimental dataset was obtained by extensive boundary layer wind-tunnel simulations, reproducing the flow and tracer release in the mock-up of an urbanised configuration. Some test cases have been performed, considering both different configurations in the experimental data varying the incoming wind direction, the building complexity and source locations, and different model configurations such as the horizontal resolution and the form of the incoming wind vertical profile.

A sensitivity analysis of the results obtained by the modelling simulations in different configurations of MicroSwiftSpray was performed in the context of the EXPO-URB model intercomparison, based on the evaluation of the predictions by four different modelling systems versus the concentration values measured at 72 points in 51 locations and at different heights. For the sensitivity, different grid resolutions of the input flow, 5 m, 3 m and 2 m, were adopted in MicroSwift, a logarithmic and a power-law input wind profiles were considered, different values of the surface layer and turbulence parameters were used. A subset of the related MicroSwiftSpray simulation results are here presented and discussed, highlighting both its positive behaviour and the agreement between predictions and observations, and the possible critical issues that may affect the model performance. A quantification of the model performance is provided based on the statistical analysis applied for the model intercomparison carried out during the project.

## THE EXPERIMENTAL SETUP AND MicroSpray Simulations

The experiments have been conducted in the Environmental Wind Tunnel Laboratory (EWTL) at Hamburg University. Here we present the results of the sensitivity analysis applied to the test case T1.1, as described in detail in the main contributions presenting the EXPO-URB Project (see Leitl et al., 2025; Trini Castelli et al., 2025). In Table 1, the setup of the wind tunnel experiment for the selected test case T1.1 is reported, together with the configuration of the subset of MicroSwiftSpray model simulations discussed here.

**Table 1**. Setup of the wind tunnel experiment for the T1.1 test case and PMSS configuration

| | |
|---|---|
| **SETUP OF THE T1.1 EXPERIMENT** | |
| **Geometry** | Level 2 – dense building |
| **Stability** | Neutral |
| **Source** | Coordinates: 430.4 North/Lat/Y [m]; 2.4 East/Lon/X [m] 20 Height/Z [m] |
| | Type: stack |
| | Diameter: D = 2 m |
| | Height over (flat) roof: 2 m |
| | Emission rate: 2 g/s ( = kBq/s) (WT) |
| **Flow** | Exit temperature: 20 °C |
| | Exit velocity: 2 m/s |
| | Roughness: $z_0$ = 0.6 m |
| | Reference height: 100 m |
| | Reference wind speed: 10 m/s |
| | Wind direction: 0° (360°) |
| **PMSS CONFIGURATION** | |
| **MicroSwift Grid domain** | 1700m×1700m ×500m; 5-m horizontal spacing; stretched vertical spacing from 1 m to 200 m |
| **Input wind profile to MicroSwift** | W1. Logarithmic, $u_*$=0.78 m/s; $z_0$=0.6 m; $d$=0m<br>W2. Power-law: $u_{ref}$= 10 m/s; $z_{ref}$=100 m; α=0.23 |
| **Background Turbulence in MicroSwift** | T1. Hanna parameterization<br>T2. As in ARTM2.1<br>T3. As in ARTM 3.0 |
| **MicroSpray concentration calculation** | Kernel approach (Barbero et al., 2024) |

For the sensitivity analysis, here we discuss the results obtained using two different wind profiles in input to MicroSwift, a logarithmic one (Eq. 1) and a power-law one (Eq. 2).

$$u(z) = \frac{u_*}{k} ln\left(\frac{z-d}{z_0}\right) \quad (1)$$

$$u(z) = u_{ref}\left(\frac{z-d}{z_{ref}-d}\right)^{\alpha} \quad (2)$$

In MicroSwift, the turbulence is calculated by superposing a background value, using boundary-layer parameterisations for the large scale, and the additional turbulence in the zones of the flow affected by its interaction with the buildings. For the background turbulence, here we used three different parameterisations for the wind velocity standard deviations and the Lagrangian time scales, in neutral stratification: Hanna et al. (1982), typically used for the SPRAY model (set of Eqs. 3, hereafter indicated as 'HANNA'), and, for comparison, two alternative formulations adopted in the ARTM model (Hanfland et al., 2024), indicated here as ARTM2 (set of Eqs. 4) and ARTM3 (set of Eqs. 5). The obstacle-induced turbulence is then summed to the background value using a scheme based on the local wind shear and a mixing length derived as a function of the minimum distance to buildings, assuming the equilibrium between production and dissipation terms (Trini Castelli et al., 2018).

HANNA parameterisation, with Coriolis parameter *f=0.0001*

$$\sigma_u(z) = 2u_* e^{-3fz/u_*};\ \sigma_v(z) = 1.3u_* e^{-2fz/u_*};\ \sigma_w(z) = 2u_* e^{-2fz/u_*}$$

$$T_{Lu}(z) = T_{Lv}(z) = T_{Lw}(z) = 0.5\frac{z}{\sigma_w(z)\left(1 + 15\frac{fz}{u_*}\right)} \quad (3)$$

ARTM2 parameterisation, with planetary boundary-layer height $h_m$=1000m, von Karman constant $\kappa$=0.4, Kolmogorov constant $C_0$=5.7

$$\sigma_u(z) = 2.4u_* e^{-z/h_m};\ \sigma_v(z) = 1.8e^{-z/h_m};\ \sigma_w(z) = 1.3u_* e^{-z/h_m}$$

$$T_{Lu,v,w}(z) = \frac{2\sigma_{u,v,w}^2}{C_0\eta} \quad (4)$$

$$\eta = max\left\{\frac{u_*^3}{\kappa z}\left[\left(1-\frac{z}{h_m}\right)^2 + \frac{z}{h_m}\right]; \frac{u_*^3}{\kappa z}\right\}$$

ARTM3 parameterisation, with $h_m$=1000m, $\kappa$=0.4

$$\sigma_u(z) = 2.4u_*;\ \sigma_v(z) = 2u_*;\ \sigma_w(z) = 1.3u_* e^{-0.9z/h_m}$$

$$T_{Lu,v,w} = \frac{K_{u,v,w}}{\sigma_{u,v,w}^2} \quad (5)$$

$$K_{u,v} = 0.9\frac{u(z)h_m}{100u_*}\sigma_{u,v};\ K_w = \kappa u_* z\left(e^{\frac{-3.6z}{h_m}}\right)^{0.5}$$

## RESULTS AND DISCUSSION

Both input wind profiles agree well with the measured values in their range, but a certain difference occurs close to the surface, where the logarithmic profile achieves significantly lower values, and to a lesser extent at higher vertical levels (see Figure 1). The impact of the wind velocity input profile on the concentration pattern is rather negligible, as can be seen from the maps in Figure 1.

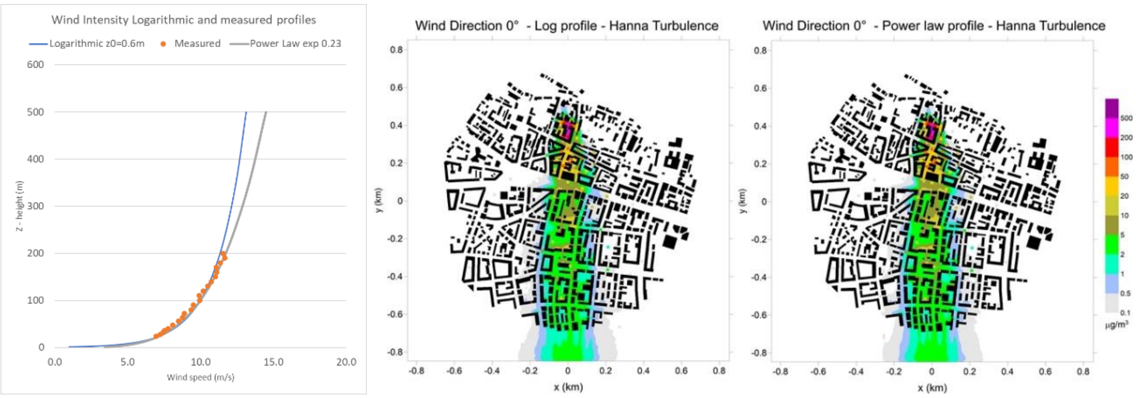


**Figure 1.** Left: wind profiles used in input to PMSS (see Table 1), logarithmic (blue line) and power law (grey line), compared to the observed data (orange points). Right: corresponding contour plots of the concentration at 2 m height.

In Figure 2 the profiles of the wind velocity standard deviations $\sigma_i$ and of the Lagrangian time scales $TL_i$ are plotted for the three different parameterisations. The HANNA horizontal components, $\sigma_{u,v}$ are lower close to the surface and ARTM2-3 show a good agreement with the observed values, while a better agreement for HANNA than ARTM2-3 parameterisations is found for the vertical component, $\sigma_w$. Larger differences are instead found for the $TL_i$, where the major differences between HANNA and ARTM parameterisation are close to the surface for ARTM3 and at high levels for ARTM2. Looking at the first 50-m layer, which is the one more affected by the urban canopy, an estimate of the difference can be provided by the weighted means, reported in Table 2. They show that ARTM2-3 generate significantly higher values than HANNA. We verified that the $TL_i$ occur to play the main role in differentiating the opening of the plume and corresponding dispersion. This was also proved by maintaining the HANNA standard deviation parameterisation but assigning a constant value to $TL_i$, like 100 s to the horizontal and 10 s in the vertical (not shown).

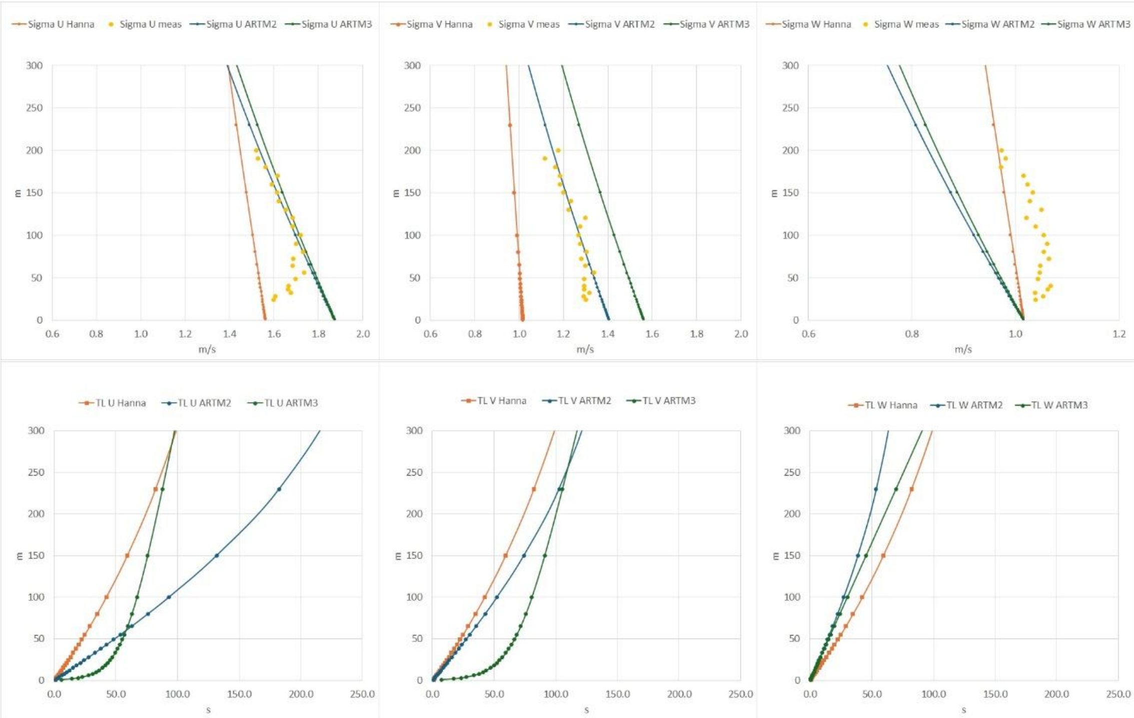


**Figure 2**. Background turbulence profiles used in MicroSwift (see Table 1), for wind velocity standard deviations (top) and Lagrangian time scales (bottom) by HANNA (dark orange line), ARTM2 (blue line), ARTM3 (green line) parameterisations and observed values (orange dots): *u* (left), *v* (middle) and *w* (right) components.

**Table 2**. Mean values of wind velocity standard deviations and Lagrangian time scales for the three parameterisations, in the first 50 m height.

| | $\sigma_u$ *(m/s)* | | | $\sigma_v$ *(m/s)* | | | $\sigma_w$ *(m/s)* | | |
|---|---|---|---|---|---|---|---|---|---|
| | HANNA | ARTM2 | ARTM3 | HANNA | ARTM2 | ARTM3 | HANNA | ARTM2 | ARTM3 |
| **mean** | 1.55 | 1.82 | 1.83 | 1.01 | 1.37 | 1.52 | 1.01 | 0.99 | 0.99 |
| | $TL_u$ *(s)* | | | $TL_v$ *(s)* | | | $TL_w$ *(s)* | | |
| | HANNA | ARTM2 | ARTM3 | HANNA | ARTM2 | ARTM3 | HANNA | ARTM2 | ARTM3 |
| **mean** | 13.66 | 29.31 | 44.76 | 13.66 | 16.49 | 53.71 | 13.66 | 8.60 | 8.93 |

In Figure 3 the maps of the concentrations are reproduced as contour plots, and highlight the effect of the different parameterisations in the final pattern of the plume. It can be seen that with ARTM2-3 choice the plume is larger, and in particular the lower values of the concentration cover a larger area. A quantification of the agreement between the predicted concentrations and the observed values at 72 points is provided through the metrics in Table 3: Fractional Bias (FB), Normalised Mean Square Error (NMSE), Index of Agreement (IA), Geometric Mean Bias (MG) and Geometric Mean Variance (VG). The results from the different simulations are comparable for most statistics. Using HANNA formulations leads to higher values of MG and VG, which are related to an underestimation of the concentration values in the medium range, reflecting the narrower concentration pattern in Figure 3.

**Table 3.** Statistical metrics for the different MicroSpray simulations

| **Metric** | **Wind log-law Hanna Turb** | **Wind log-law ARTM2 Turb** | **Wind log-law ARTM3 Turb** | **Wind Power-law Hanna Turb** |
|---|---|---|---|---|
| **FB** | -0.03 | 0.11 | 0.22 | -0.03 |
| **NMSE** | 0.84 | 0.80 | 1.09 | 0.85 |
| **MG** | 2.44 | 1.81 | 1.31 | 2.49 |
| **VG** | 11.55 | 5.27 | 7.63 | 12.52 |
| **IA** | 0.98 | 0.98 | 0.98 | 0.98 |

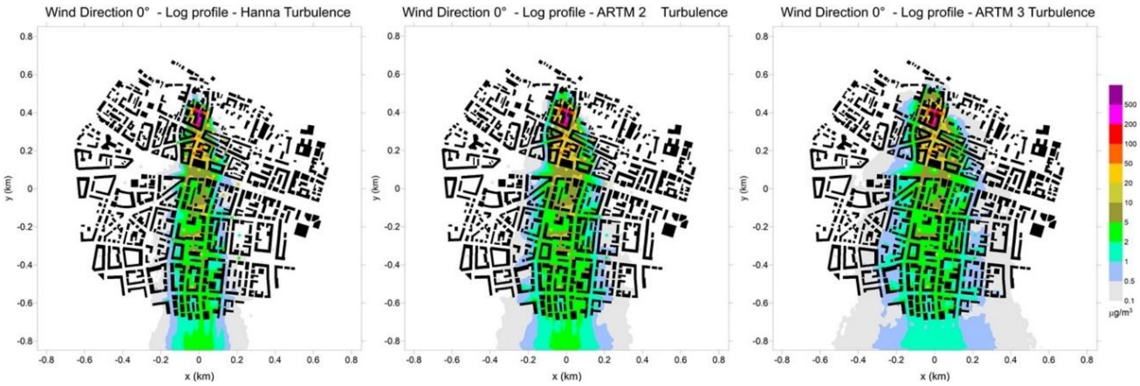


**Figure 3**. Contour plots of the concentration field at 2 m height for the wind-profile logarithmic law and turbulence by Hanna (left), ARTM2 (middle) and ARTM3 (right)

## CONCLUSIONS

The sensitivity analysis conducted through the presented PMSS simulations in application to EXPO-URB wind-tunnel experiments highlighted the importance of the input fields assigned to the modelling system. It enabled evaluating to what extent the final results depend on the driving fields, in particular showing a significant impact of the turbulent quantities. The different parameterisations considered in this study led to significantly different Lagrangian time scale values. We found a certain sensitivity of the plume spreading to their values, particularly in the horizontal direction. The wind velocity standard deviations, in this case, induced a lesser effect, despite the different formulations used to calculate them.

However, in the region with high concentration values no major differences occur when applying alternative parameterisations. This is certainly an important aspect, since for population and environmental protection, high concentration values are of greater concern.

We should consider whether parameterisations designed for larger scales may be critical in representing background turbulence at microscale. This can be even more true when considering built environments and when reproducing the flow and dispersion simulated in wind tunnel experiments. Additional simulations for a variety of case studies are ongoing, allowing us to achieve more robust statistics and results that can be generalised in a finer way.

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